Original Article

# Effect of variety and cooking method on resistant starch content of white rice and subsequent postprandial glucose response and appetite in humans

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Rice is a staple carbohydrate throughout much of the world. Previous work indicated that resistant starch (RS) content of rice consumed in India varied with rice variety and cooking method. This study quantified RS in 4 white rice varieties (jasmine, long grain, medium grain, and short grain) cooked in three manners (oven baked, conventional rice cooker, and pressure cooker), and analyzed for RS content immediately after preparation or after 3 days of refrigeration at 4°C. The rice varieties with the highest and lowest RS content were selected for a pilot-scale trial to characterize postprandial glycemic response and appetite ratings in healthy adults (n=21). Refrigerated long-grain rice cooked in a conventional rice cooker had the highest RS content (HRS, 2.55 g RS/100 g) and refrigerated short-grain rice cooked in a pressure cooker had the lowest RS content (LRS, 0.20 g RS/100 g). These rice samples were served reheated in the clinical trial. Glucose area under the curve (AUC) were significantly lower with HRS and LRS compared to glucose beverage; however, there was no difference between HRS and LRS. Glycemic indices did not differ significantly between HRS and LRS. Subjects reported an overall increased feeling of fullness and decreased desire to eat based on incremental area under the curve (iAUC) for both HRS and LRS compared to control. This study found that RS naturally occurring in rice had minimal impact on the postprandial glycemic response and appetite.

**Key Words: resistant starch, rice, glycemic index, appetite, satiety**

## INTRODUCTION

Resistant starch (RS) is naturally found in starchy foods such as potato, corn and rice. Due to its chemical nature and low digestibility, RS is considered a type of dietary fiber. Resistant starch is classified into four subtypes based on its physicochemical properties. Type 1 (RS1) is physically inaccessible starch granules, ie seeds. Type 2 (RS2) is native granular starch, such as that found in potato and banana. Type 3 (RS3) is retrograded starch made by cooking/cooling processes on starchy materials. Type 4 (RS4) is chemically modified starch. Foods containing RS3 have relatively reduced digestible carbohydrate content, while dietary fiber content is relatively increased.

Resistant starch escapes digestion in the stomach and small intestine and enters into the large intestine, where it may be fermented by colonic microbiota to produce short chain fatty acids which lower the colonic pH.[1] Additionally, systemic effects of RS include improving the insulin sensitivity[2,3] and decreasing the postprandial blood glucose and insulin response in healthy subjects and subjects with elevated fasting glucose.[3-6] However, not all studies have shown reduction in glycemic response or fasting glucose concentrations after RS consumption.[7,8] These differences may be attributed to food form, source of RS, and subject characteristics.

Rice is a staple carbohydrate source in many Asian countries. The consumption of rice has gradually increased within the United States during the past decade, even though rice is not a staple carbohydrate of the American diet.[9] Rice cultivars vary in RS content; RS content is dependent on original amylose content. Resistant starch content may be increased during food processing, cooling, and storage.[10] Current data on RS content of rice are inconsistent, ranging from 0.8 g to 26.1 g per cup of cooked rice.[11] Although the GI of rice has been studied by several groups, this is the first study to consider RS content when evaluating postprandial glycemic response to rice.[12,13] Resistant starch from rice has the potential to improve human health; however, RS content must first be better characterized, and subsequent clinical trials are necessary to confirm a physiological benefit. The objectives of the present study were to 1) determine the effect of cooking method and refrigeration on RS content of 4 varieties of commonly consumed white rice; and 2) assess the impact of RS on postprandial glucose response and appetite ratings in 21 healthy adults. This study hypothesizes that rice variety will significantly impact RS content, and rice

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with high RS content will result in a lower postprandial glycemic response.

## MATERIALS AND METHODS

### *Determination of RS in rice*

A survey of available rice varieties was conducted in four major supermarkets in Honolulu, Hawaii, USA. The most common brands of short-grain, medium-grain, long-grain, and jasmine rice were selected for analysis. Each rice variety was cooked using each of three different methods (oven baked, conventional rice cooker, and pressure cooker). In the oven baked method, 1 cup rice was combined with 1.5 cup water and baked in a covered glass baking dish at 175ºC for 30 minutes. In the conventional rice cooker (Aroma®, San Diego, CA USA), 1 cup rice was combined with 1.5 cups water and cooked until the rice cooker turned off (20-30 minutes cooking time). In the pressure cooker method (Presto® stove top pressure cooker, Eau Claire, WI USA, 1 cup rice was combined with 4 cup water and cooked for 6 minutes under pressure. The remaining water was strained from the rice. A portion of rice was refrigerated immediately after preparation. Resistant starch content of fresh rice was measured immediately after preparation, while RS content of refrigerated rice was measured after 3 days of storage at 4ºC.

Resistant starch was measured by AOAC Official Method 2002.02, using a commercially available assay kit (Megazyme International, Ireland). All samples were analyzed in duplicate. Unless otherwise noted, all reagents were obtained from Sigma-Aldrich (St Louis, MO, USA). Fresh rice samples were prepared for RS analysis immediately after cooking. Refrigerated rice were removed from the refrigerator and reheated prior to RS analysis. Each rice sample was ground using a mortar and pestle. The sample (0.5 g) was combined with 4 mL pancreatic α-amylase (10 mg/mL) containing amyloglucosidase (3 U/mL). Samples were incubated in a shaking water bath at 37°C, with continuous shaking for 16 hours. Upon removal from the water bath, ethanol (4 mL, 99% v/v) was added to each sample, and samples were vortexed. The samples were then centrifuged at 2,000 g for 10 minutes. Supernatants were decanted. Pellets were re-suspended with 2 mL ethanol (50% v/v) and vortexed. Additional ethanol (6 mL, 50% v/v) was added, the tubes were vortexed and then centrifuged at 2,000 g for 10 minutes. The suspension, vortex and centrifuge steps were repeated twice.

A magnetic stir bar and 2 mL potassium hydroxide (2 M) were added to each remaining pellet. Samples were stirred and incubated in an ice water-bath for 20 minutes. Sodium acetate buffer (8 mL, 1.2 M, pH 3.8) was added to each tube, and 0.1 mL amyloglucosidase (3300 U/mL) was added immediately after. The tubes were mixed and placed in a water bath at 50°C for 30 minutes. Samples were centrifuged at 2,000 g for 10 minutes. Aliquots (0.1 mL) of supernatants were transferred into clean glass test tubes. Glucose oxidase/peroxidase reagent was added into test tubes and tubes were incubated in a water bath at 50°C for 20 minutes. Immediately upon removal, absorbance was measured at 510 nm compared with a reagent blank (0.1 mL of 100 mM sodium acetate buffer (pH 4.5) with GOPOD reagent) by spectrophotometer (Shimadzu UV-160U, Kyoto, Japan). Based on the RS analysis, the rice samples with the highest and lowest RS content were selected for use in the clinical study.

### *Determination of glucose response and appetite ratings after rice consumption*

Twenty-one healthy adults (12 men and 9 women) were recruited from the University of Hawaii at Manoa and nearby communities via flyers and posters. Eligibility criteria included: 1) age between 18 and 65 years old; 2) non-smoker, non-vegetarian and not under any medication(s); 3) must eat breakfast regularly; 4) be able to fast for 12 hours and attend three morning study visits. Exclusion criteria included: 1) pregnancy or lactating; 2) have been diagnosed with disease(s) or take medication(s); 3) smoker, and/or vegetarian; 4) gain or lost weight greater than 10 lbs in the past three months; 5) currently enrolled in other clinical studies; 6) have a restricted eating habit; 7) have a fasting blood glucose level >126 mg/dL. The research project was approved by the University of Hawaii Committee on Human Studies (CHS), and written consent was obtained from the subjects after a full explanation of consent and methods of the study.

Prior to the first study visit, subjects completed an eating habits questionnaire to identify any restricted eating habits[14] and a health history questionnaire to confirm health status. Fasting blood glucose concentration was measured with an OneTouch® Ultra blood glucose meter (LifeScan) to ensure subjects were not diabetic (blood glucose <126 mg/dL). Study visits were completed no less than two days apart. Subjects completed a 1-day diet record on the day prior to the study visit. On the morning of the study visit, subjects arrived fasted (prior 12 hours). The study was a randomized, single-blind crossover study. At each study visit, subjects consumed one of three treatments: glucose beverage (control, 50 g glucose), high RS rice (HRS), and low RS rice (LRS). All rice treatments were reheated in the microwave prior to serving to the study subjects. The cooked rice portions contained 50 g available carbohydrate, each (HRS: 4.4 g RS/50 g available carbohydrate, LRS: 0.4 g RS/50 g available carbohydrate). Subjects' fasting blood glucose was measured at the beginning of the study visit (time 0). Subjects were immediately presented with the test rice or glucose beverage and were required to consume the treatment within 15 minutes. Blood glucose measurements were taken at 15, 30, 45, 60, 90, and 120 minutes during the 2 hour study visit. Blood glucose area under the curve (AUC) was calculated using the trapezoidal rule. Glycemic index for HRS and LRS was calculated based on the glucose response AUC.[15]

Appetite survey was assessed with a 100 mm visual analogue scale (VAS). The subjects answered the following appetite survey questions at 0, 15, 30, 45, 60 and 120 minutes: "How hungry are you?" 0 = Not hungry at all and 100 = I have never been more hungry; "How satisfied do you feel?" 0 = I am completely empty and 100 = I cannot eat another bite; "How full do you feel?" 0 =Not full at all and 100 = Totally full; "How much do you think you can eat?" 0 = Nothing at all and 100 = A lot. The VAS ratings were quantified by measuring the distance from the left end of the scale to the point marked by

**Table 1.** Resistant starch content (g RS/100 g prepared rice, mean±SE) in 4 varieties of white rice, prepared by different cooking methods

| Variety | Fresh | | | p-value | Refrigerated | | | p-value |
|---|---|---|---|---|---|---|---|---|
| | Pressure | Rice cooker | Oven | within fresh varieties† | Pressure | Rice cooker | Oven | within refrig. varieties† |
| Jasmine | $0.53 \pm 0.01^{aAB}$ | $0.92 \pm 0.02^{b}$ | $0.95\pm 0.02^{bA}$ | 0.001 | $0.41\pm0.02^{a*}$ | $0.74\pm0.12^{bA}$ | $0.38\pm0.03^{aA*}$ | 0.001 |
| Long Grain | $0.58 \pm 0.02^{A}$ | $1.08 \pm 0.27$ | $0.72 \pm 0.01^{B}$ | 0.206 | $0.47\pm0.23^{a}$ | $2.55\pm0.74^{bB}$ | $0.67\pm0.08^{aB}$ | 0.002 |
| Medium Grain | $0.37 \pm 0.08^{AB}$ | $0.49 \pm 0.12$ | $0.27 \pm 0.01^{C}$ | 0.296 | $0.26\pm0.51^{a}$ | $0.86\pm0.3^{bA}$ | $0.34\pm0.09^{aA}$ | 0.004 |
| Short Grain | $0.29 \pm 0.02^{B}$ | $0.38 \pm 0.06$ | $0.38 \pm 0.01^{D}$ | 0.316 | $0.20\pm0.07^{a}$ | $0.81\pm0.26^{bA}$ | $0.23\pm0.07^{aA}$ | 0.007 |
| p-value within cooking method‡ | 0.028 | 0.075 | <0.0001 | | 0.080 | 0.001 | 0.001 | |

†Within a row of fresh or refrigerated samples, cells with different lower case superscripts are significantly different ($p$<0.05). ANOVA Model RS = cooking method, data grouped by variety and fresh/refrigerated, n=2
‡Within a column, cells with different upper case superscripts are significantly different ($p$<0.05), ANOVA Model RS = variety, data grouped by cooking method and fresh/refrigerated, n=2
*Indicates that resistant starch was significantly different between fresh and refrigerated samples (within variety and cooking method), t-test $p$< 0.05.

**Table 2.** Demographics (n = 21)

| | Men/Women (n) | Age (yr) | Height (m) | Weight (kg) | BMI (kg/m$^2$) |
|---|---|---|---|---|---|
| Mean | 12/9 | 29.33 | 1.70 | 66.2 | 22.9 |
| Range | -- | 22-57 | 1.47-1.90 | 49.1-102.7 | 18.5-30.1 |

the participant. All measurements were reported in millimeters. Appetite AUC was calculated using the trapezoidal rule.

Dietary intake data were collected and analyzed using the Nutrition Data System for Research software version 4 (2010), developed by the Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN. Total energy, fat, protein, carbohydrate, saturated fatty acids, monounsaturated fatty acids, polyunsaturated fatty acids, total dietary fiber, soluble dietary fiber and insoluble fiber were analyzed.

### *Statistical analysis*

Data were analyzed with SAS statistical software (Version 9.1.3, North Carolina, USA). Results are presented as mean±SD. Resistant starch content was compared among rice varieties and cooking methods using ANOVA (PROC GLM). Effect of refrigeration was determined using the *t*-test. Treatment effects on blood glucose concentrations and appetite ratings were determined using PROC MIXED to control for subject variation. Significant differences were determined at $p$<0.05.

## RESULTS

### *Effect of cooking method and variety on RS content of rice*

Within the fresh rice, cooking method did not significantly affect RS content of long grain, medium grain, or short grain rice varieties (Table 1). Pressure cooking significantly reduced the RS content of fresh jasmine rice, compared to the rice cooker and oven baking. Within the pressure cooked and oven baked rice, rice variety had a significant effect on RS content of fresh rice. Resistant starch content of refrigerated rice was significantly impacted by cooking method, with the rice cooker consistently producing higher RS content within a variety. Rice variety significantly influenced RS content of refrigerated rice when rice was prepared with a rice cooker and when baked in the oven. Refrigeration significantly decreased the RS content of pressure cooked and oven baked Jasmine rice, but had no effect on the other rice varieties or cooking methods. Refrigerated long grain rice prepared with the rice cooker had the highest RS content (2.55 g RS/100 g as-eaten rice). Refrigerated short grain rice prepared with the pressure cooker had the lowest RS content (0.20 g RS/100 g rice). These two rice varieties were selected for use in the glycemic response trial.

### *Effect of RS on glycemic response and appetite*

Baseline demographics of the study subjects are shown as average and range of each characteristic in Table 2. Mean fasting blood glucose concentrations (t=0) were not different among treatment groups (Table 3). Blood glucose concentrations differed significantly at 30 min, 45 min, and 60 min, with glucose control resulting in higher concentrations than HRS and LRS. Glucose AUCs were significantly lower for HRS and LRS compared to glucose control. There was no statistical difference between the GI of the two rice treatments. Macronutrient intake and energy intake did not differ among treatment groups (Table 4). The decreased appetite scores (Figure 1A, Figure 1D) and negative AUC represent (Figure 2) a decreased feeling of hunger and decreased desire to eat. The increased appetite scores (Figure 1B, Figure 1C) and the increased AUC (Figure 2) represent an increased feeling of satisfaction and increased feeling of fullness. Appetite ratings did not differ significantly at each individual time point (Figure 1). Subjects reported significantly increased fullness and significantly lower desire to eat after consuming HRS and LRS compared to glucose control based

**Table 3.** Mean blood glucose concentrations (mmol/L, mean ± SE)

| Treatment | Glucose beverage | High RS rice | Low RS rice |
|---|---|---|---|
| 0 Min | 5.36 ± 0.13 | 5.33 ± 0.13 | 5.14 ± 0.11 |
| 15 Min | 8.13 ± 0.28 | 7.67 ± 0.20 | 7.38 ± 0.24 |
| 30 Min | 9.29 ± 0.23[a] | 8.27 ± 0.26[b] | 7.93 ± 0.21[b] |
| 45 Min | 8.98 ± 0.41[a] | 7.66 ± 0.28[b] | 7.57 ± 0.24[b] |
| 60 Min | 8.07 ± 0.37[a] | 7.38 ± 0.31[b] | 6.71 ± 0.26[b] |
| 90 Min | 6.92 ± 0.35 | 6.58 ± 0.27 | 5.99 ± 0.23 |
| 120 Min | 5.06 ± 0.28 | 5.76 ± 0.22 | 5.55 ± 0.18 |
| Total AUC | 264 ± 24.4 | 211 ± 14.1 | 181 ± 12.0 |
| Glycemic index | -- | 83.9 ± 6.6 | 78.0 ± 10.6 |

Different letters indicate that the data in the same column were significantly different between control and rice treatments, ANOVA ($p$<0.05)

on the total AUC (Figure 2).

## DISCUSSION

Rice has been considered a carbohydrate with low to moderate dietary fiber content, based on total dietary fiber analysis (0.6-3.5 g dietary fiber/1 cup prepared rice)[16,17] and resistant starch analysis (1.9-3.4 g RS/1 cup prepared rice).[18] However, resistant starch content varies with cooking process (steamed, boiled, strained, or pressure cooked) and rice cultivar, ranging from 0.8-26.1 g RS/1 cup prepared rice.[11] Walter *et al*, reported similar RS content, although the range of values was not as great as Rashmi *et al.*[11,19] Results from this study were similar to or lower than previous reports. This may be attributed to cooking method and rice cultivar.

Carbohydrate digestibility is influenced by intrinsic

**Table 4.** Dietary intake during 24 hours prior to study visit (mean ± SE)

| | Glucose Beverage | High RS Rice | Low RS Rice | $p$ |
|---|---|---|---|---|
| Energy Intake (kcal) | 2330 ± 218 | 2369 ± 219 | 2069 ± 176 | 0.12 |
| (kJ) | 9755 ± 912 | 9917 ± 917 | 8662 ± 739 | |
| Total Fat (g) | 102 ± 13.9 | 97.7 ± 12.6 | 82.1 ± 10.4 | 0.43 |
| Saturated FA | 31.6 ± 4.1 | 31.6 ± 4.4 | 29.8 ± 4.2 | 0.48 |
| MUFA | 40.2 ± 6.6 | 37.4 ± 5.1 | 29.9 ± 4.2 | 0.50 |
| PUFA | 21.8 ± 3.3 | 20.3 ± 2.9 | 15.3 ± 1.8 | 0.27 |
| Total carbohydrate (g) | 253 ± 20.7 | 264 ± 22.1 | 243 ± 20.5 | 0.05 |
| Total protein (g) | 104 ± 11.9 | 108 ± 11.4 | 93.0 ± 7.4 | 0.27 |
| Total dietary fiber (g) | 21.0 ± 2.4 | 18.9 ± 2.2 | 18.5 ± 2.3 | 0.24 |
| Soluble fiber | 5.9 ± 1.0 | 5.2 ± 0.6 | 5.6 ± 0.7 | 0.19 |
| Insoluble fiber | 15.0 ± 1.8 | 13.3 ± 1.8 | 14.2 ± 2.3 | 0.77 |

n =21, ANOVA was used to compare dietary outcomes across treatments

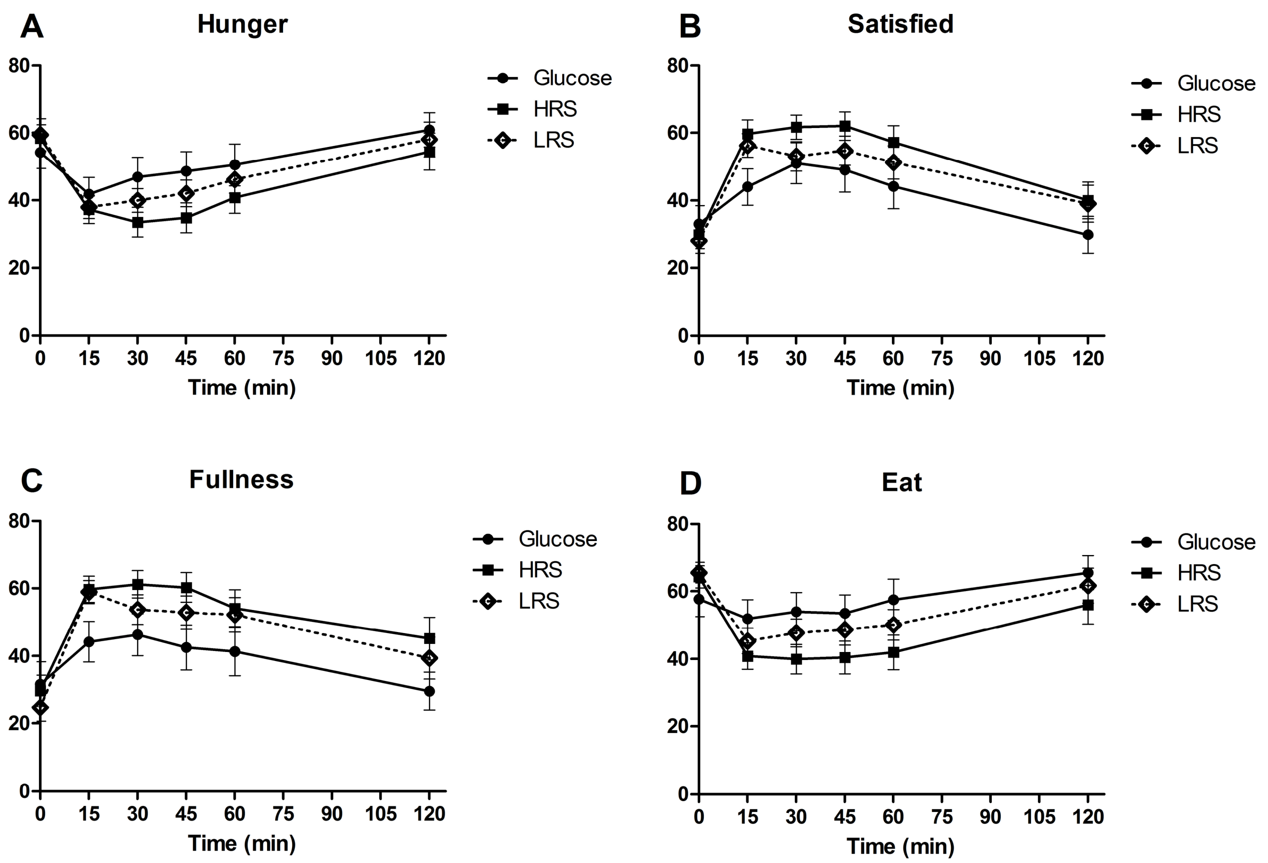


**Figure 1.** Mean appetite rating in response to glucose beverage and rice treatments over time (n=21)

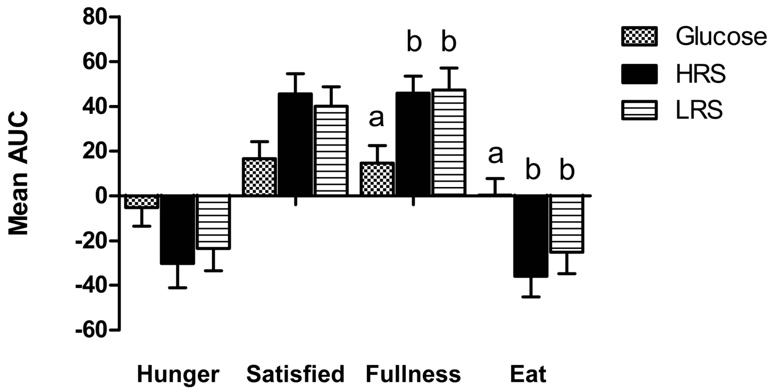


**Figure 2.** Total appetite ratings AUC (n=21). AUC is the area under the appetite rating-time curve from 0 to 2 hr after consumption.

factors (eg food forms, granule shape and crystalline structure, etc) and extrinsic factors (eg other food components). The rate of digestion in different rice varieties is modified due to the effect of cooked-rice particle size, preparation, cooking procedures (eg cooking time, heat treatment), and storage methods on their chemical structures (eg amylose).[11,20,21] Rice varieties with similar amylose content can result in different starch digestion rate and glycemic response due to different physicochemical properties (eg gelatinization) and the factors previously mentioned.[21] Jung *et al*[22] reported that uncooked rice with less gelatinization resulted in lower glycemic and insulin response than cooked rice. Gelatinization is correlated with digestibility of starch and metabolism responses.

Besides the cooling and drying processes, another confounding factor that has been considered to alter the RS content and the degree of RS formation is the length of chill storage. Ma *et al* indicated that the grain structure of various cooked rice was significantly affected by chill storage time.[23] Cold room cooling method, a longer cooling process, resulted in a higher rate of retrogradation than air blast cooling (immediate cooling). In addition, Ma *et al* also claimed amylose content alters the retrogradation that can easily occur with high-amylose content rice varieties at 0-4°C.[23] In the present study, the state of gelatinization was not measured. The rice in this study was stored for 3 days at 4°C prior to RS analysis or consumption. Longer storage has the potential to increase RS content; however microbial growth could render the rice unfit for consumption. Including these characteristics in future studies may provide for a better understanding of RS formation in foods.

White rice is typically considered a high GI food, as previously reviewed by Atkinson *et al*.[24] While the mean GI reported in this review was 73, the range of published GI values was quite wide: 43-94. This emphasizes the importance of considering rice variety and cooking method when making a generalization about the glycemic response to rice. Recently, GI for three Indian varieties of rice was evaluated for against glucose as the reference food (50 g available carbohydrate).[13] The GIs of the Indian rice were slightly lower than those reported in our study, ranging 70.2-77. As early as 1992, amylose content of rice was identified as a characteristic that could reduce the glycemic index of rice.[12] Further research on high-amylose varieties of rice is necessary to fully understand the variability in rice GI. The high GI of white rice is associated with higher risk of type 2 diabetes, particularly in Asian populations. The dose-response analysis showed that each serving a day of white rice consumption was significantly associated to an 11% increase in risk of diabetes in the overall population. Therefore, identification of lower GI rice may be protective against chronic disease development.[25] A recent clinical trial also showed that ethnicity impacts GI of rice, with self-reported Chinese subjects experiencing a higher GI in response to some rice varieties than European subjects.[26]

Increasing consumption of RS has shown beneficial effects on postprandial blood glucose and insulin concentrations in people with either normal or impaired blood glucose concentrations. Yamada *et al* [4] reported that a single ingestion of bread containing 6 g RS significantly inhibited postprandial glucose and insulin responses in subjects with fasting blood glucose >110 mg/dL. The treatment had no effect on subjects with fasting blood glucose <110 mg/dL. Behall *et al* [27] reported that the consumption of test muffins providing several combining levels of β-glucan and RS (β-glucan intake averaged 0.3, 0.9, and 3.7 g and RS intake averaged 0.9, 3.4, and 6.5 g, respectively) resulted in a reversal relationship of postprandial blood glucose and insulin responses. The combination of resistant starch with β-glucan showed a greater decrease in glucose and insulin than RS or β-glucan consumed alone. Moreover, subjects who continuously consumed breads containing 8-13.4 g RS showed a significant reduction of glucose and insulin responses.[28] Maize-derived RS needed to be consumed at the 15-30 g level to improve insulin sensitivity in overweight or obese men, and this effect was not seen in women.[29] A clinical trial showed that a RS supplement (48 g RS) had no significant effect on the appetite and postprandial glycemic response in healthy adults.[30] It is likely that the dose of 4.4 g RS was not sufficient to observe a change in glycemic response acutely, particularly in healthy adults.

In subjects with impaired fasting glucose (diabetics, prediabetics), this treatment has the potential to reduce glucose AUC with chronic consumption. A daily dose of 6 g RS from rice, consumed for 4 weeks, significantly decreased postprandial glucose concentrations in diabetic and prediabetic subjects.[31] Chronic consumption of resistant starch is hypothesized to improve insulin sensitivity and insulin secretion. The beneficial effects of RS may only be evident with long term intake, which may explain why this acute study showed no difference in postprandial glycemic response.

The amount of rice consumed in the present study was a realistic serving size (1-1/4 cups cooked rice), and the RS dose in this study was realistically obtainable from foods as part of a normal, healthy diet. The length of refrigeration storage is the maximum safe storage time, provided that the rice was chilled immediately after preparation.[32] The rice samples selected for the clinical trial had the greatest difference in RS content (0.20 g RS vs 2.55 g RS/100 g rice as-eaten). We expected that, due to the difference in RS content, that these samples would have the greatest likelihood of eliciting a different glycemic response, postprandially.

The present study found no differences in appetite ratings between rice treatments; however subjects felt more full and desired to eat less after consuming the rice compared with the glucose beverage. A similar finding was reported by Ranawana *et al*: Basmati rice made subjects feel significantly less hungry, more full, and with a lower desire to eat compared to a sucrose sweetened beverage.[33] The increased fullness and satisfaction are likely due to the solid nature of the rice. However, RS has been linked with appetite suppression and decreased energy intake.[30,34] Resistant starch content of rice could influence appetite ratings, but further work is necessary to explore this mechanism. The maximum dose consumed in this study (4.4 g RS) may not be sufficient, and long-term studies are more appropriate for evaluating this effect.

### *Conclusion*

This study demonstrated that RS content of rice is variable, dependent on rice variety and cooking method. Although the rice samples studied had significantly different RS content, these differences did not result in physiological differences in postprandial glycemic response in healthy adults. The study was limited by a small sample size and the acute nature of the study. Future work should evaluate RS content of novel varieties of rice and determine postprandial glucose response in a higher-risk group, such as adults with elevated fasting blood glucose concentrations.

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## AUTHOR DISCLOSURES

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## REFERENCES

1. Chen HL, Cheng HC, Wu WT, Liu YJ, Liu SY. Supplementation of konjac glucomannan into a low-fiber Chinese diet promoted bowel movement and improved colonic ecology in constipated adults: A placebo-controlled, diet-controlled trial. J Am Coll Nutr. 2008;27:102-8.
2. Johnston KL, Thomas EL, Bell JD, Frost GS, Robertson MD. Resistant starch improves insulin sensitivity in metabolic syndrome. Diabet Med. 2010;27:391-7. doi: 10.1111/j.1464-5491.2010.02923.x
3. Robertson MD, Currie JM, Morgan LM, Jewell DP, Frayn KN. Prior short-term consumption of resistant starch enhances postprandial insulin sensitivity in healthy subjects. Diabetologia. 2003;46:659-65.
4. Yamada Y, Hosoya S, Nishimura S, Tanaka T, Kajimoto Y, Nishimura A et al. Effect of bread containing resistant starch on postprandial blood glucose levels in humans. Biosci Biotechnol Biochem. 2005;69:559-66. doi: 10.1271/bbb. 69.559
5. Haub MD, Hubach KL, Al-Tamimi EK, Ornelas S, Seib PA. Different types of resistant starch elicit different glucose reponses in humans. J Nutr Metab. 2010;2010:230501. doi: 10. 1155/2010/230501
6. Brouns F, Arrigoni E, Langkilde AM, Verkooijen I, Fassler C, Andersson H et al. Physiological and metabolic properties of a digestion-resistant maltodextrin, classified as type 3 retrograded resistant starch. J Agric Food Chem. 2007;55: 1574-81. doi: 10.1021/jf062057w
7. Higgins JA, Higbee DR, Donahoo WT, Brown IL, Bell ML, Bessesen DH. Resistant starch consumption promotes lipid oxidation. Nutr Metab (Lond). 2004;1:8.
8. Pasman W, Wils D, Saniez MH, Kardinaal A. Long-term gastrointestinal tolerance of NUTRIOSE FB in healthy men. Eur J Clin Nutr. 2006;60:1024-34. doi: 10.1038/sj.ejcn.1602 418
9. Batres-Marquez SP, Jensen HH, Upton J. Rice consumption in the united states: Recent evidence from food consumption surveys. J Am Diet Assoc. 2009;109:1719-27. doi: 10.1016/ j.jada.2009.07.010
10. Liu Q, Donner E, Yin Y, Huang RL, Fan MZ. The physicochemical properties and in vitro digestibility of selected cereals, tubers and legumes grown in china. Food Chemistry. 2006;99:470-7. doi: 10.1016/j.foodchem.2005.08.008
11. Rashmi S, Urooj A. Effect of processing on nutritionally important starch fractions in rice varieties. Int J Food Sci Nutr. 2003;54:27-36. doi: 10.1080/096374803/61976
12. Miller JB, Pang E, Bramall L. Rice: A high or low glycemic index food? Am J Clin Nutr. 1992;56:1034-6.
13. Shobana S, Kokila A, Lakshmipriya N, Subhashini S, Ramya Bai M, Mohan V et al. Glycaemic index of three indian rice varieties. Int J Food Sci Nutr. 2012;63:178-83. doi: 10. 3109/09637486.2011.615300
14. Stunkard AJ, Messick S. The three-factor eating questionnaire to measure dietary restraint, disinhibition and hunger. J Psychosom Res. 1985;29:71-83. doi: 10.1016/0022-3999(85) 90010-8
15. Wolever TM. Effect of blood sampling schedule and method of calculating the area under the curve on validity and precision of glycaemic index values. Br J Nutr. 2004;91:295-301. doi: 10.1079/BJN20031054
16. U.S. Department of Agriculture, Agricultural Research Service. USDA National Nutrient Database for Standard Reference, Release 22. Nutrient Data Laboratory Home Page. 2009. [Accessed 11/27/2009] Available at: http://www.ars. usda.gov/ba/bhnrc/ndl, 2010.
17. U.S. Department of Agriculture, Agricultural Research Service. 2012. USDA National Nutrient Database for Standard Reference, Release 25. [Accessed 03/24/2013] Nutrient Data Laboratory Home Page. Available from: http://www.ars.usda. gov/nutrientdata
18. Murphy MM, Douglass JS, Birkett A. Resistant starch intakes in the united states. J Am Diet Assoc. 2008;108:67-78. doi: 10.1016/j.jada.2007.10.012
19. Walter M, Picolli da Silva L, Denardin CC. Rice and resistant starch: Different content depending on methodology. J Food Comp Anal. 2005;18:279-85. doi: 10.1016/j.jfca.20 04. 09.007

20. Patindol JA, Guraya HS, Champagne ET, McClung AM. Nutritionally important starch fractions of rice cultivars grown in southern united states. J Food Sci. 2010;75:H137-44. doi: 10.1111/j.1750-3841.2010.01627.x
21. Panlasigui LN, Thompson LU, Juliano BO, Perez CM, Yiu SH, Greenberg GR. Rice varieties with similar amylose content differ in starch digestibility and glycemic response in humans. Am J Clin Nutr. 1991;54:871-7.
22. Jung EY, Suh HJ, Hong WS, Kim DG, Hong YH, Hong IS et al. Uncooked rice of relatively low gelatinization degree resulted in lower metabolic glucose and insulin responses compared with cooked rice in female college students. Nutr Res. 2009;29:457-61. doi: 10.1016/j.nutres.2009.07.002
23. Ma Y, Sun D. Hardness of cooked rice as affected by varieties, cooking method, and chilled storage. J Food Process Eng. 2009;32:161-76. doi: 10.1111/j.1745-4530.2007.00206.x
24. Atkinson FS, Foster-Powell K, Brand-Miller JC. International tables of glycemic index and glycemic load values: 2008. Diabetes Care. 2008;31:2281-3. doi: 10.2337/dc08-1239
25. Hu EA, Pan A, Malik V, Sun Q. White rice consumption and risk of type 2 diabetes: Meta-analysis and systematic review. BMJ. 2012;344:e1454. doi: 10.1136/bmj.e1454
26. Kataoka M, Venn BJ, Williams SM, Te Morenga LA, Heemels IM, Mann JI. Glycaemic responses to glucose and rice in people of chinese and european ethnicity. Diabet Med. 2012;30:e101-7. doi: 10.1111/dme.12080
27. Behall KM, Scholfield DJ, Hallfrisch JG, Liljeberg-Elmstahl HG. Consumption of both resistant starch and beta-glucan improves postprandial plasma glucose and insulin in women. Diabetes Care. 2006;29:976-81. doi: 10.2337/dc 05-2012
28. Behall KM, Hallfrisch J. Plasma glucose and insulin reduction after consumption of breads varying in amylose content. Eur J Clin Nutr. 2002;56:913-20. doi: 10.1038/sj.ejcn.1601411
29. Maki KC, Pelkman CL, Finocchiaro ET, Kelley KM, Lawless AL, Schild AL et al. Resistant starch from high-amylose maize increases insulin sensitivity in overweight and obese men. J Nutr. 2012;142:717-23. doi: 10.3945/jn.11 1.152975
30. Bodinham CL, Frost GS, Robertson MD. Acute ingestion of resistant starch reduces food intake in healthy adults. Br J Nutr. 2010;103:917-22. doi: 10.1017/S0007114509992534
31. Kwak JH, Paik JK, Kim HI, Kim OY, Shin DY, Kim HJ et al. Dietary treatment with rice containing resistant starch improves markers of endothelial function with reduction of postprandial blood glucose and oxidative stress in patients with prediabetes or newly diagnosed type 2 diabetes. Atherosclerosis. 2012;224:457-64. doi: 10.1016/j.atherosclerosis.2012.08.003
32. Gilbert RJ, Stringer MF, Peace, TC. The survival and growth of Bacillus cereus in boiled and fried rice in relation to outbreaks of food poisoning. J Hyg. 1974;73:433-44. doi: 10.1017/S0022172400042790
33. Ranawana V, Henry CJ. Liquid and solid carbohydrate foods: Comparative effects on glycemic and insulin responses, and satiety. Int J Food Sci Nutr. 2011;62:71-81. doi: 10.3109/09637486.2010.520011
34. Willis HJ, Eldridge AL, Beiseigel J, Thomas W. Slavin JL. Greater satiety response with resistant starch and corn bran in human subjects. Nutr Res. 2009;29:100-5. doi: 10.1016/j.nutres.2009.01.004

Original Article

# Effect of variety and cooking method on resistant starch content of white rice and subsequent postprandial glucose response and appetite in humans

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# 不同白米種類與烹煮方式對抗性澱粉產生之影響及其人體餐後血糖與食慾之變化

在許多國家之中，稻米是平日飲食中澱粉攝取的主要來源。印度的研究指出，稻米因品種及烹煮方式不同，其抗性澱粉含量有明顯的差異。本研究利用四種不同品種的稻米(jasmine、long grain、medium grain 及 short grain)，並以三種不同的烹煮方式(烤箱、電鍋及壓力鍋)處理後，來檢測其抗性澱粉含量的變化。米樣品分別於烹煮後立即分析其抗性澱粉含量，以及 4°C 冷藏保存三天後，進行第二次定量分析。本研究根據四種稻米經過不同烹煮方式的抗性澱粉含量結果，選取其中最高及最低含量的米樣品做為下一階段臨床試驗，給予 21 位健康受試者食用，用以探討稻米中抗性澱粉的含量多寡是否能影響人體之餐後血糖及食慾。在所有米樣品中，發現使用電鍋烹煮再經過冷藏處理的長米(long grain)為最高的抗性澱粉含量(HRS, 2.55 g RS/100 g)。而以壓力鍋烹煮再經過冷藏後的圓米(short grain)為最低含量(LRS, 0.20 g RS/100 g)。因此，受試者食用加熱過的此兩種米樣品，並於兩小時內，定時檢測餐後血糖及食慾變化。結果顯示，HRS 及 LRS 餐後血糖之曲線下面積顯著低於葡萄糖，但比較 HRS 及 LRS 對於餐後血糖的影響及其昇糖指數，皆無統計上的差異。此外，對於食慾的影響，受試者表示食用 HRS 及 LRS 比葡萄糖有顯著地增加飽足感，並且有效降低多食用的慾望。綜合研究結果表示，存在此四種稻米中的天然抗性澱粉含量，對於人體餐後血糖及食慾之影響並非十分明顯。

**關鍵字：抗性澱粉、米、昇糖指數、食慾、飽足感**